ASYNCHRONOUS START OF LARGE UNIT IN PUMPED STORAGE HPP "ČAPLJINA" IN PRESENT POWER SYSTEM OF BOSNIA AND HERZEGOVINA

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ABSTRACT: According to the European Community plan POWER III, the rehabilitation of the power system of Bosnia and Hercegovina (BiH) and its reconnection with Croatian power system should be completed by the end of 2005. Use of available resources under constraints imposed by actual and prospective states of the power systems of BiH and Croatia (particularly Adriatic lines) leads to operational problems: violation of (n-1) criteria, high voltages, voltage instability, thermal power plants (TPPs) operating below minimum, etc. Having outstanding capabilities, pumped storage HPP Čapljina (2x240 MVA) could contribute to mitigating some of those problems while fully exploiting its advantages on the open electricity market. Two system services should be provided for HPP Čapljina: asynchronous start (with and/or without phase reactors at the generator starpoint) and transmission capacity for pumping. To find out if these services are available before rehabilitation of the power system a study was done and results are outlined in this paper. Regarding voltage / reactive power dynamics, asynchronous start of units at HPP Čapljina with phase reactors is possible, but reactive capability of nearby generators is fully used. With the other machine at HPP Čapljina operating as generator voltage/reactive power conditions in this part of the system are significantly improved. Two variants of supplying power for pumping were considered, from TPPs in BiH and from UCTE. In the latter case the constraint is violation of the (n-1) criterion for Adriatic lines in the Croatian power system.

Key words: pumped-storage hydro power plant, asynchronous start, pumping, system services, dynamic simulation

I. INTRODUCTION

Power system of Bosnia and Herzegovina (BiH) has been severely damaged during the war 1992-1995. Pre-war BiH transmission network and the actual state is shown scematically in fig.1. Rehabilitation and reconnection of BiH power system with power system of Croatia is planned to be completed by the end of 2005 (European Community POWER III plan). In the meantime, reduced availability of transmission network (400 and 220 kV) causes many operational problems and prevents full use of some plants' capabilities.

One of such plants is pumped-storage hydro power plant (PS HPP) Čapljina (2x240 MVA, commissioned in 1979), situated in the southern part of BiH power system. It is connected via two 220 kV transmission lines (37.4 km, 2x360mm^2 AlFe) to 220 kV bus Mostar 4 which was connected in the pre-war system by two 400 MVA transformers to the 400 kV network (so called "Adriatic Line"). The plant was designed for night pumping/daily peak operation (typically 225 days/year), and for generator operation (typically 140 days/year, 12-14 hours/day in favourable hydrological conditions) and also as synchronous compensator (±150 Mvar). In the pre-war power system (1990) all foreseen regimes were possible with no limitations, including asynchronous start of the units into motor operation with or without phase reactors at the starpoint.

Since beginning of the war HPP Čapljina, although not damaged itself, has been operating with significant restrictions. Pumping has not even been attempted because of the belief that the damaged system would be too weak to support asynchronous start of the units. On the other hand, the importance of this plant to the system can be illustrated by the following figures: in 1991 its total electricity production was 481.925 MWh, with 110 starts into motor operation and 6 starts into compensator regime. Total number of starts since 1979 was 1621, and in 1990 there was the highest annual number of starts (258). In the period 1982-1991 total energy for pumping amounted to 1,774 206 MWh, resulting in the production of 1,312 912 MWh from pumping with the very high ratio equal to 0.74. To fully exploit its outstanding capabilities it was decided to investigate possibilities and necessary conditions for asynchronous start and pumping of HPP Čapljina units in the present power system of Bosnia and Herzegovina and neighbouring power system of Croatia (particularly with respect to its southern part and "Adriatic Line"). To that purpose a study was performed to provide the necessary answers from the system point of view. The study comprised: (i) steady state analysis with particular observation of voltage profile/reactive power support, (ii) short circuit calculation in order to determine system short circuit capacity (i.e. system "stiffness"), and (iii) dynamic simulation of chosen scenarios of asynchronous starts.

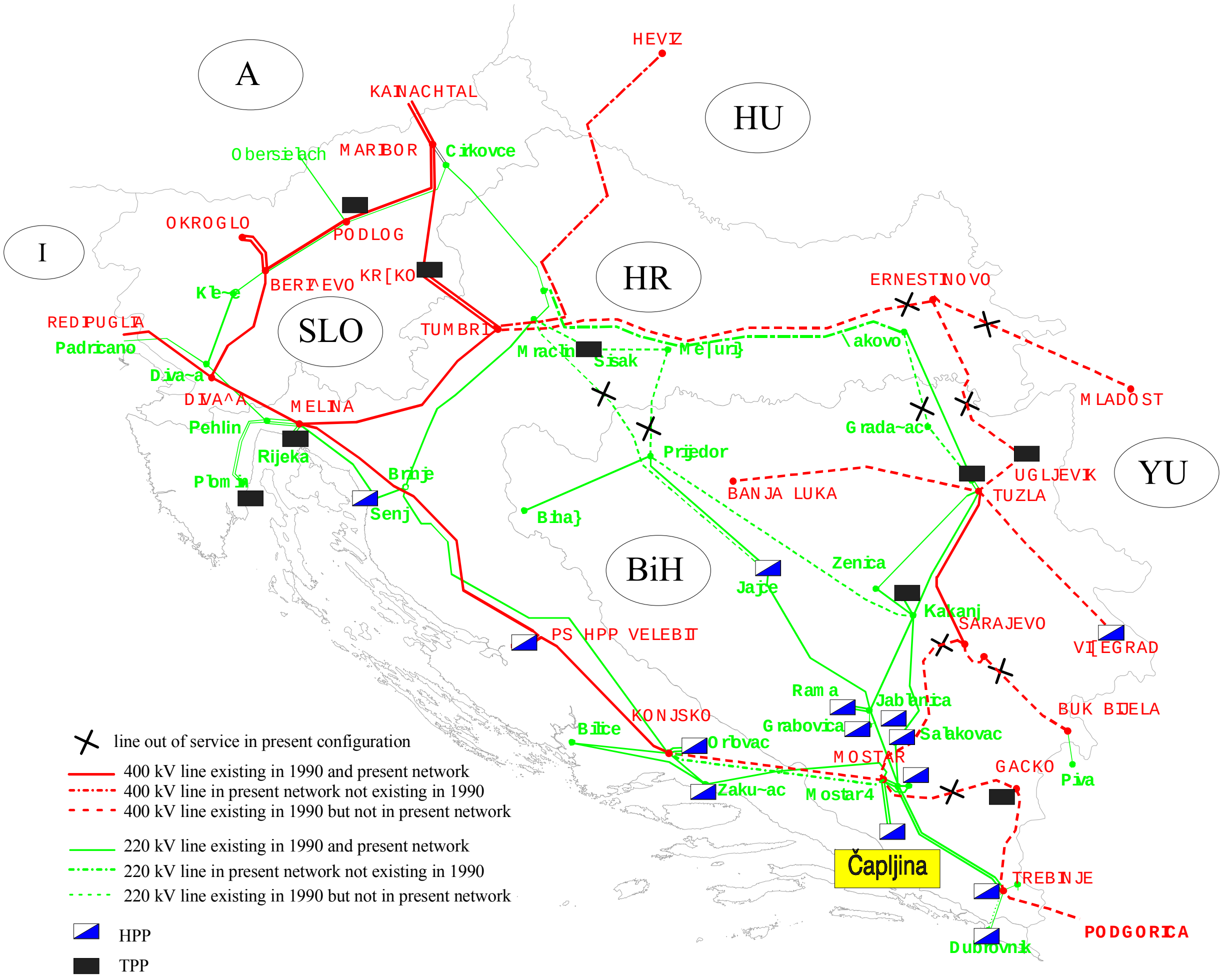


Figure 1 Power system of BiH and neighbouring power systems – pre-war state (1990) and actual configuration

II. STEADY STATE ANALYSIS

A Load flow analysis

Having in mind actual power system condition in the region of Herzegovina (BiH) and Dalmatia (Croatia), special attention has been payed to system security issues. According to UCTE recommendations each member should take care of minimizing risk of unwanted influence of disturbances in its own system to neigbouring systems. This is of special importance in case of major power plants such as HPP Čapljina connected to relatively weak transmission network. Currently, power system of BiH is connected through Croatian power system to UCTE (I. synchronous zone) via interconnection lines Mostar 4 – Konjsko (400 kV, operating under 220 kV), Mostar 4 – Zakučac (220 kV) and Tuzla – Đakovo (220 kV). It should be noted that HPP Čapljina is radially connected to 220 kV bus Mostar 4.

Power system model for steady state analysis comprised power system models the part of the BiH system being in the I. UCTE synchronous zone (400, 220 and 110 kV levels), and power systems of Croatia and Slovenia.(400 and 220 kV levels), with slack bus in Divača. All generating units were modelled with unit transformers and it was assumed that voltage regulators would keep nominal voltage at generator terminals within actual capability chart limits.

Steady state analysis was performed for assumed actual network configuration, light load condition (night period) and several variants of generator scheduling. The following system state(s) have been considered: (i) immediately before asynchronous start, (ii) during the start (one quasi-steady state), (iii) after synchronization of the unit at HPP Čapljina to the system, and (iv) during pumping. On basis of this analysis minimum requirements to the power system have been established.

According to operation experience and previous field test results (1979), the system should provide approximately 20 MW and 200 Mvar during asynchronous start of one unit at HPP Čapljina with phase reactors at the starpoint and with no water in turbine. Obviously, this is primarily voltage/reactive power problem. Basic requirement for succesful asyncronous start is that the power system must be "stiff" enough (sufficient short circuit capacity at the connection point) and should have sufficient reactive power reserve in order to prevent excessive voltage sags in the network during the start.

In case of HPP Čapljina both power systems of BiH and Croatia would play key role in providing system service of supporting asynchronous start.

Two of several considered network configuration/generator scheduling cases were found acceptable:

BC-1 - with one generator at HPP Rama and one generator at HPP Dubrovnik, and

BC-2 - with one generator scheduled at each of the HPPs near Mostar 4 (Rama, Salakovac, Grabovica) but without HPP Dubrovnik.

In both cases one generator at HPP Zakučac in Dalmatia was assumed to be in operation. In given conditions all generators had sufficient reactive power reserve for supporting asynchronous start. Analysis results are briefly summarized in figs. 2 and 3. Reactive power outputs of selected generators (for states immediately before and during asynchronous start in both above described cases) are shown in bar-graph form in fig. 2 along with generator reactive capabilities. Voltage profiles in the representative 220 kV nodes before and during start are shown in fig. 3. Bus voltages were initially rather high (night period of daily load diagram) and in both cases remained above nominal values during the start (fig 3). In both cases reactive capability of nearby generators was fully used, i.e. without any safety margin. To provide additional reactive power support during the start it was decided to operate the other unit at HPP Čapljina in generator-compensator regime with rated voltage at the generator terminals.

B. Short circuit calculation results

As already mentioned, short circuit currents and powers at connection point are important indices of system capability to support asynchronous start. Short circuit capacity at the connection point should be greater than certain minimum value ((i.e. equivalent system impedance should be less than certain maximum value). This critical value can be determined on a single machine – inifinite bus model by applying criteria that the machine current, bus voltage drop and duration of start are kept below acceptable limits. In the case of HPP Čapljina this value is about 3600 MVA at 220 kV bus Mostar 4. This value is very convenient for practical purposes because it could be verified in the real system by measuring the equivalent reactance of the system seen from 220 kV bus at HPP Čapljina once the desired system state is established.

Since HPP Čapljina is connected radially to the system in the 220 kV node Mostar 4, short circuit calculations have been done for that node. It was assumed that the power system is in the state immediately before asynchronous start. Given the initial short circuit current I_k'' the initial (subtransient) three-phase short circuit power S_k'' is calculated according to:

$$S_k^{"} = c \cdot \sqrt{3} \cdot U_n \cdot I_k^{"} \qquad (1)$$

where c=1 for minimum short circuit [1].

Short circuit results are summarized in table 1. Short circuit levels for cases with 400 kV network partially restored and with transmission network fully restored according to the POWER III project are given here for comparison.

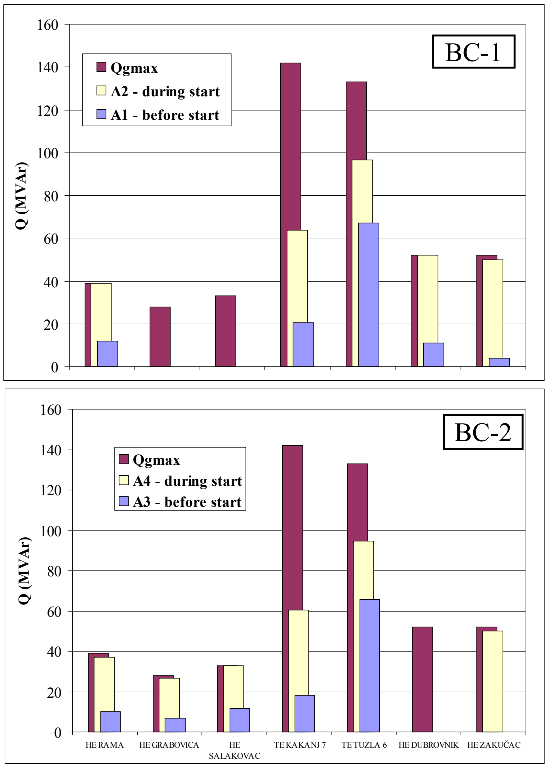


Figure 2. Generator reactive powers before and during the start, cases BC-1 and BC-2

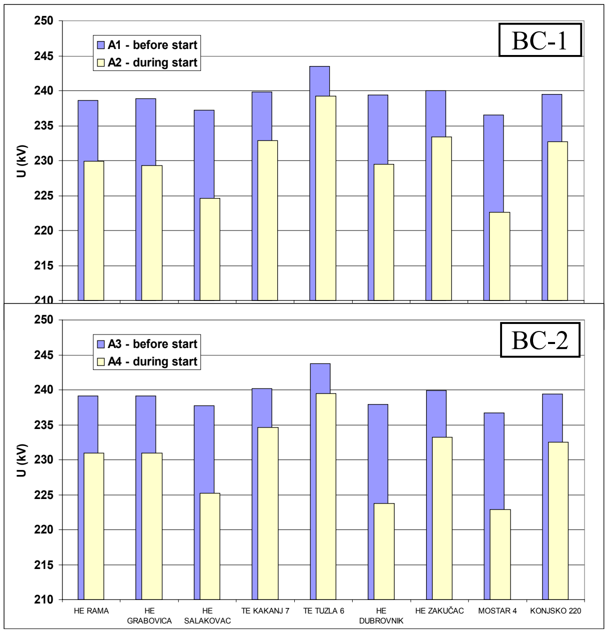


Figure 3. Bus voltages (220 kV) before and during the start, cases BC-1 and BC-2

Table 1 Short circuit calculation results for Mostar 4

CASE	**$U_{Mostar\ 4}$ (pre-fault) (kV)**	**I''_{3F} (kA)**	**S''_{3F} (MVA)**
BC-1 (with HPP Dubrovnik 220 kV)	236.5	8.184	3348
BC-2 (with HPP Salakovac and HPP Grabovica)	237.7	8.925	3671
Base case(BC-1) + TL 400kV Sarajevo 10-Mostar 4–Konjsko and transformation at Mostar4 -2x400MVA	244.5	9.513	4040
Peak load 2005 (after completion of the 'POWER III' project)	241	18.167	7574

The base case with HPP Dubrovnik has the lowest short circuit level which is near/slightly under the estimated critical value (3600 MVA) and the base case variant with HPP Salakovac and Grabovica has only marginally higher short circuit level. In both cases it was obviously necessary to check system behaviour by performing dynamic simulations of the start. With 400 kV network partially restored the situation becomes favourable while in the last case with fully restored network the short circuit level exceeds the value of 7000 MVA in which case even direct asynchronous start (without the phase reactors) would be possible.

III. DYNAMIC SIMULATION RESULTS

Simulations of system dynamics during asynchronous start of one unit at HPP Čapljina with phase reactors in its starpoint were performed on the multimachine model of the BiH power system and relevant parts of the neighbouring Croatian system (the same extent as in steady state analysis). Excitation systems with automatic voltage regulators and maximum field current limiters as well as turbine governors were modelled for all generators represented with subtransient models. Model parameters were determined on basis of available equipment data.

The motor/generator at HPP Čapljina was represented with the equivalent double-cage induction machine. Its parameters were determined by fitting the model response against the time responses of the actual machine during start, recorded in 1979.

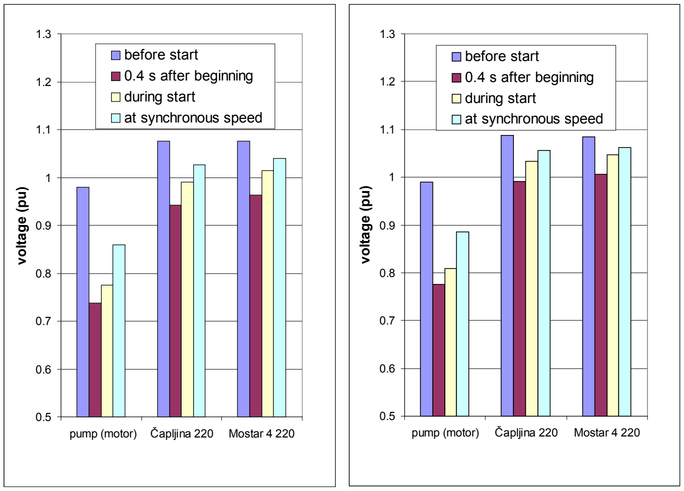
The main purpose of the dynamic simulation was to confirm the preliminary conclusion based on steady state analysis that the asynchronous start could be succesfully performed in given system conditions. It should also make planning and performing of field tests easier by providing deeper insight into system dynamic behaviour during the process.

Two cases were simulated:

AS-1) asynchronous start of one motor/generator without support of the other machine at HPP Čapljina in which case the power system is responsible for providing entire reactive power support (200 Mvar) as a system service

AS-2) asynchronous start of one motor/generator at HPP Čapljina with the other machine operating in generator/compensator regime at rated voltage, in which case the system service is reduced by approximately 50%

Thirty-two quantities (motor/generator speed, bus voltages, generator active and reactive powers, active and reactive power flows in transmission lines, generator angles,...) were monitored during the simulation. Simulation results for both cases are illustrated simultaneously in Fig. 5 by time diagrams of representative variables. Values of bus voltages at four characteristic moments are compared in fig. 4 for both cases (AS-1 and AS-2). Duration of the start up to reaching the synchronous speed is 126 seconds. The system response is stable and machine oscillations are well damped. Bus voltages remain above the limits all the time during the start. As expected from steady state analysis, in case AS-1 generators at HPP Zakučac, HPP Rama and HPP Dubrovnik reached their maximum reactive power in the overexcited region. Naturally, in case AS-2 bus voltage deviations are even smaller and none of the generators reached its reactive power limit due to support of the other machine at HPP Čapljina. Duration of the start was 115 seconds. In either case there was no operation of overexcitation limiters.



AS-1 AS-2

Fig. 4 Representative bus voltages at characteristic moments during asynchronous start

This dynamic simulation results confirmed that it would be possible to perform asynchronous start in given "minimum" conditions. These results proved also very useful in the process of planning actual field tests.

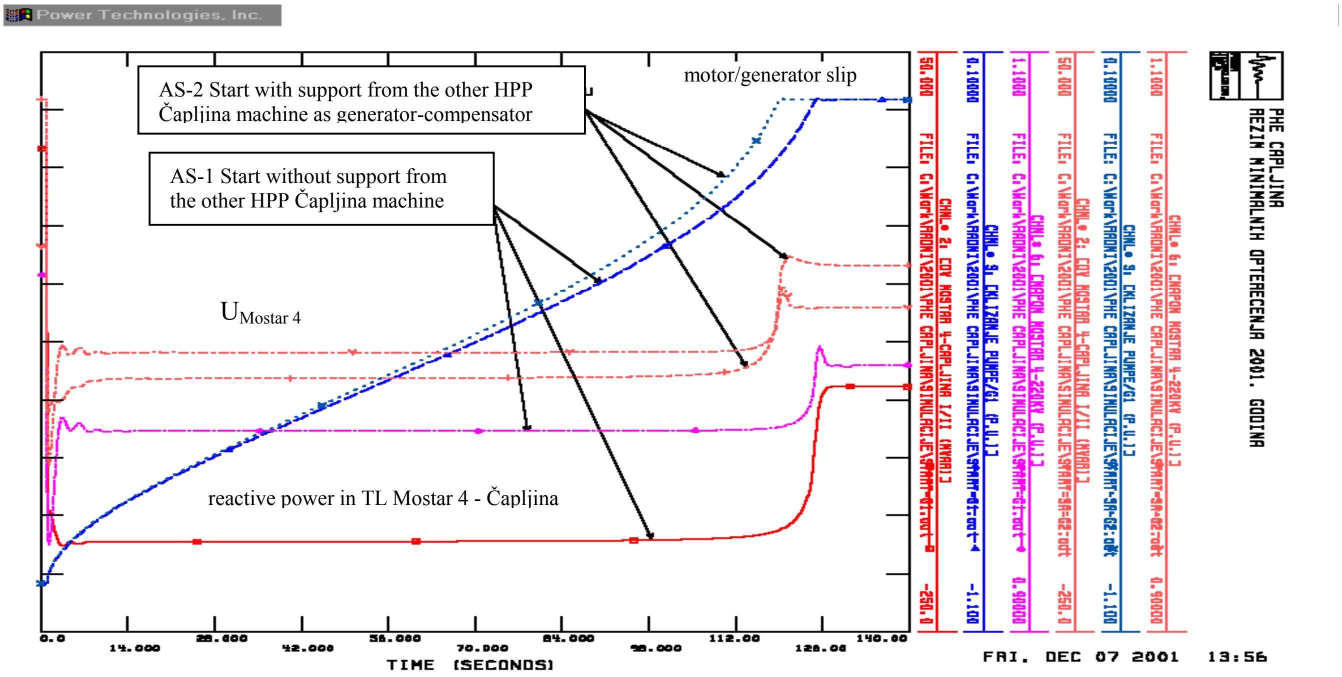


Figure 5 . Results of asynchronous start dynamic simulations, cases AS-1 and AS-2 – time diagrams of representative variables

IV. TRANSMISSION CAPACITY NECESSARY FOR PUMPING

In two characteristic cases electric power and energy required for pumping can be secured:

PC-1) from UCTE interconnection, in which case the Croatian power system must provide transmission capacity for that service

PC-2) from power plants within power system of BiH.

In the first case (PC1) practically the entire power for pumping is transported over transmission network in Dalmatia (southern Croatia). Security criterion (n-1) is not satisfied since the outage of the 400 kV line Melina – Velebit results in overloading and outage of the 220 kV line Brinje – Konjsko followed by the outage of the 220 kV line Tuzla – Đakovo, leading eventually to separation of power systems of Dalmatia, Bosnia and Herzegovina from UCTE, probably ending with voltage and frequency collapse, i.e. total blackout in the so formed island. This scenario obviously requires careful operational planning and precisely defined procedures in order to prevent spreading of disturbances.

The second case (PC-2) is more favourable because in that scenario there are no (n-1) security limitations (also thermal generating unit outage??). Besides, available (coal-fired) thermal power plants in the BiH, which sometimes were operating at or even below their technical minimum (using oil), can be more economically used. At the same time transmission costs for pumping could be significantly reduced compared to case PC-1.

V. CONCLUSION

Steady-state analysis results indicated that security of BiH power system and neighbouring power systems would not be endangered during asynchronous start of one unit at HPP Čapljina with phase reactors at the starpoint and with no water in tne turbine. Short circuit capacity at Mostar 4 node depends much on the actual system configuration and generator scheduling. Before the 400 kV network is restored it is about the critical level. Reactive power support from nearby generators is of utmost importance so that their actual reactive power capabilities, at this stage determined from capability charts, must be revised taking into account effects of automatic voltage regulators and associated limiting devices. This was done, on basis of available data, in dynamic simulations.

Results of dynamic simulations confirmed the preliminary conclusion and gave valuable insight into system dynamic behaviour. All system quantities are within acceptable limits but nearby generators are pushed to their reactive power limits. If the other machine at HPP Čapljina operates as generator/compensator prior to and during the asynchronous start, requirements from the system are significantly decreased. Since that means safer start and reduced risk to the system, this variant is to be preferred and should become regular operating scenario, at least until the transmission system is fully restored.

Finally, actual system behaviour should be tested by performing corresponding field tests. These tests should be carefully planned and should cover system-wide monitoring of relevant plants. Study results should be extensively used in preparing the tests, i.e. for checking settings of protection devices, defining requirements to recording devices, investigate scenarios in case of unsuccesful start and so on.

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VII BIOGRAPHIES

N.Rusanov was born in 1946. at Karlovac, Croatia. He received his degree in 1971 at the Elctrotehnical faculty. At the same university, in 1983. he finished M. Sc. degree and made final dissertation about voltage regulation of generators and transmission networks.

Same year when he received diploma, he was employed by the Enterprise for production, transmission and distribution electrical energy “Elektroprivreda Bosnia & Herzegovina”. Immediately he started with scientific investigation. In this time, his firm formed dynamic model of electrical power system (micro network), and he made some projects and constructed specific equipment for this laboratory. Since 1985. till beginning war he was head of this laboratory.

His professional orientation are load flow analysis, voltage and reactive power regulation in transmission networks and dynamic stability in power systems. Hi is the author a lot of essays about these problems end results were applied in Power system BiH. Before 1991. he was a member of some expert groups of JUGEL (ex Yugoslavia) and he published more then 30 professional essays in journals and consultations.

Since 1987. he was a secretary of JUKO CIGRE (former Yugoslavia) Study Committee 38. After established BiH Committee CIGRE, he is the Chairman of Study Committee 38. In this moment, he is elected to observer member of the International Committee CIGRE, SC 38.

S. Vucina was born at Mostar, Bosnia and Herzegovina. He received his B.S. degrees from Faculty of Electrical Engineering, University of Sarajevo in 1975. Since 1978 he was working as leading engineer for equipment for HPP Grabovica (2x57 MW). Since 1984 he was working in numerous search and development hydro projects, and special interconnection projects of HPP with Power system. Hi is the author a lot of papers on the field HPP and the systems of uninterruptible power supply. He is an outstanding specialist in field of power sources of wind, water and trash.

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